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Sir:

The below-identified communication(s) is (are) submitted in the above-captioned application or proceeding:

☒ Certified copy of Australian Provisional Application No. 2003903838

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I, MICHELLE HENKEL, TEAM LEADER EXAMINATION SUPPORT AND SALES hereby certify that annexed is a true copy of the Provisional specification in connection with Application No. 2003903839 for a patent by COCHLEAR LIMITED as filed on 24 July 2003.

WITNESS my hand this
Fourteenth day of February 2006

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Battery Characterisation

Technical Field

This disclosure broadly relates to managing the charging and discharging regime of a rechargeable battery.

Background

Charge management regimes for rechargeable batteries are designed to maximise the useful life of the rechargeable battery by aligning their operating parameters with those empirically shown to be favourable for longevity. Further, such charge management regimes seek to maximise the efficiency of the battery.

The success of a charge management regime can depend on the accuracy of the input parameters used, such as the amount of charge remaining in the battery at any particular moment in time. One method of determining the charge remaining is to take measurements of the terminal voltage and use this to calculate accumulated charge.

However, this voltage correlation method can be inaccurate because of variations in a battery's charging and discharging characteristics over its lifetime. These variations can be influenced by the manner in which the battery has been previously charged and discharged, and from the operating temperature.

Another method of determining the charge remaining is to periodically sample the current flowing into or out of the battery. This method may generate a more accurate estimate of the present state of charge, and measurement gain or offset errors could be corrected using software signal processing techniques. To reduce quantisation errors when sampling, the current resolution must be small relative to both charge and discharge currents. The main drawback to this method is its high processing requirement. This is particularly the case where the charge or discharge current is not constant over time. Such sampling needs to be at rate of at least twice the highest component frequency (the Nyquist rate) of the current waveform, which may require a significant amount of processing power. In many electronic devices, this increased processing burden is impractical because of the limited space and power constraints.

Another method of determining the charge remaining is to mathematically integrate the measured charge and discharge current.

The current integration approach has been used for example in US 4,678,999 (*"Schneider"*). Similarly, US 6,049,210 (*"Hwang"*) has highlighted the usefulness of frequency measurements derived from an integrator.

US 6,504,344 (*"Adams"*) demonstrates the integration technique used over a short period of time and under a known load to characterize the battery.

The current integration approach is particularly desirable when using lithium ion batteries, because the mAh charge efficiency is regarded as being very close to unity. However, a drawback of the current integration approach is that inaccuracies can result from the inherent offsets in analogue circuitry. These offsets can be compensated for, however, this has been shown to be more difficult to achieve for lower currents.

For example, US 6,339,315 (*"Castelli"*) proposes a method that creates a 'dead zone' in which current is not integrated. However, *Castelli* requires that the charge or discharge current be sufficiently large to render the offset insignificant. Further, if calibration is required, it usually must be done before the device is used.

US 6,583,626 (*"Rosenberger"*) also proposed a method for compensation for offsets using two separate scales for integration. However, *Rosenberger* is not capable of being calibrated and is suitable for large current measurements, as would be expected on a car battery.

US 6,577,135 (*"Matthews"*) proposes a method of offset compensation suitable for small currents. However, the inaccuracy in the offset remains.

It is desired to ameliorate any one or more of the foregoing drawbacks of the prior art.

Summary

In accordance with one aspect of the invention, there is provided a method of managing a power supply for an electronic device, the power supply having a rechargeable battery source and an auxiliary power source, said method comprising the steps of:

implementing a measuring circuit to measure parametric data of the battery source during operational charging and discharging cycles with the device;

checking for temporary removal of the battery source from operation of the device; and

testing the measuring circuit for offset error, if power from the battery source has been temporarily removed, before resuming said implementing step.

In accordance with another aspect of the invention, there is provided a power supply for an electronic device, said power supply comprising:

a rechargeable battery source configured for cyclical charging and discharging during operative association with the electronic device;

a measuring circuit for measuring parametric data during said charging and discharging;

an auxiliary power source being able to power the electronic device independently of said battery source; and

a testing circuit for testing said measuring circuit for offset error;

a disconnection circuit for temporarily removing said operational association of said battery with said device;

wherein said testing circuit is enabled during said temporary removal of said operational association of said battery with said device.

In accordance with another aspect of the invention, there is provided a system for operating a rechargeable battery, said system comprising:

current maintaining means for maintaining a substantially constant current to the battery until the battery reaches a predetermined maximum voltage;

voltage maintaining means for maintaining a substantially constant voltage to the battery until a predetermined minimum current is delivered to the battery;

determining means for determining a cyclical charge value delivered to the battery by said current maintaining means and said voltage maintaining means during a cycle; and

correction means for correcting said determining means when charge is not being delivered to the battery, on the basis of said charge value.

In accordance with another aspect of the invention, there is provided an apparatus for characterising a rechargeable battery, said apparatus comprising:

a constant current source for maintaining, during a first charging stage, a substantially constant current flow to the battery, until the battery reaches a predetermined maximum voltage;

a constant voltage source for maintaining, during a second charging stage, a substantially constant voltage to the battery, until a current flow delivered to the battery falls to a predetermined minimum;

an integrator for integrating said current flow delivered to the battery during the first and second calibration stages;

threshold detection means configured to signal a unit count of charge upon detection of a predetermined level of charge indicated by the output from the integrator;

correlation means for correlating a total number of unit counts of charge during said first and second calibration stages with said predetermined maximum voltage and said predetermined minimum current.

In accordance with another aspect of the invention, there is provided a computer readable medium, having a program recorded thereon, where the program is configured to

make a computer execute a procedure to operate a rechargeable battery, said procedure comprising the steps of:

characterising the battery comprising the sub-steps of:

(i) delivering a substantially constant current to the battery until the battery reaches a predetermined maximum voltage;

(ii) delivering a substantially constant voltage to the battery until a predetermined minimum current is delivered to the battery; and

(iii) determining a delivered charge value delivered to the battery by sub-steps (i) and (ii);

cyclically delivering operational charging and discharging of the battery according to said determined delivered charge value.

Brief Description of the Drawings

An example of the present invention and its principles of operation will now be described with reference to the drawings, in which:

Fig. 1 is a graphical representation of an example rechargeable battery fading characteristics;

Fig. 2 is a functional block diagram of a re-settable measurement circuit according to this disclosure;

Fig. 3 is a flow chart of the calibration of the measurement circuit of Fig. 2;

Fig. 4 is a flow chart of a charge management algorithm, for charging and discharging a battery, according to this disclosure;

Figs 5A and 5B are each a graphical representation of charging characteristics of an initial charging cycle for the charge management algorithm of Fig. 4;

Figs 6A and 6B are each a graphical representation of charging characteristics of a subsequent charging cycle for the charge management algorithm of Fig. 4;

Fig. 7 is a plan view of a part of a totally implantable cochlear implant system;

Fig. 8 is a cross-sectional view taken along the lines VIII – VIII of Fig. 7; and

Fig. 9 is a schematic diagram of the electrical architecture used in the device of Figs 7 and 8.

Detailed Description

A starting point in developing a charge management regime for a rechargeable battery is to determine a method of measurably characterising the battery. This normally involves

determining the remaining charge capacity in the battery, which can be ascertained in a number of ways.

As earlier mentioned, the voltage of the battery can be used, in which case, a measurement is regularly taken and an algorithm is implemented that attempts to estimate the amount of useful energy stored in the battery, and therefore may approximate the time remaining until the battery must be recharged.

However, such voltage-based calculations do not take into account the fact that the voltage depends on the chemistry, the current state the chemistry is in (ageing, state of charge, both), the load, and the duration of load connection. Fading results in a reduced capacity, i.e. less charge can be stored in and retrieved from the battery. Ideally, a charge management algorithm using this voltage data would be fading-independent, but since only voltage data is known, the algorithm can only approximately compensate for fading effects.

These variations due to fading can be shown on a plot of charge versus voltage, as shown for example in Fig. 1. For a new battery, there is very little charge remaining below 3.6V, while an aged battery has an almost linear relationship between charge and voltage. When new, a charge of approximately 40% of the battery capacity would be required to charge the battery from 0 to 3V. When aged, the battery would require approximately 20% of its capacity to achieve the same result.

Consequently, voltage measurements do not represent a linear or otherwise easy-to-define relationship with the actual state of charge of a battery.

In accordance with this disclosure, an example of a re-settable measuring circuit and method will firstly be described with reference to Figs 2 and 3, respectively. Thereafter, an example application of the re-settable measuring circuit and method will be described. This application is a charge management algorithm, for charging and discharging a battery, and will be described with reference to Fig. 4.

Referring to Fig. 2, a sense resistor 31 converts the current flowing into or out of the battery 32 into a voltage drop suitable for amplification. The value of the sense resistor 31 is small so that the power of the battery 32 is not wasted on the current measurement, as this resistance will dissipate some power. This resistance is specified in commercially available current integrators in the order of 10-20mΩ.

A differential amplifier 33 is connected across the sense resistor 31 and isolates the measurement circuitry from the main power circuit carrying current flow to or from the battery 32. The differential amplifier 33 amplifies the voltage drop across the resistor 31 to a sufficiently high level, to reduce noise and provide a stable signal. The differential amplifier

33 outputs a current signal that is proportional to the current flow in or out of the battery 32, such that:

$$I_{Diff} = kI_{Batt}$$

where k is a constant.

The output current signal, I_{diff}, from the differential amplifier 33 is connected to the integrator 34. The integrator 34 consists of essentially an operational amplifier with a capacitor (C) connected between the output and the inverting input. Neglecting the effects of non-ideal circuitry, the integrator 34 produces the function:

$$V_{out} = -\int \frac{I_{Diff}}{C} dt$$

or

$$V_{out} = -k \int \frac{I_{Batt}}{C} dt$$

When the output voltage from the integrator 34 reaches a threshold value, the detection block 36 outputs a signal to the digital logic 35, indicating that a quantised unit of charge has been processed. The digital logic 35 then resets the integrator 34 by temporarily closing switch 34a which in turn discharges the capacitor 34b.

When the output voltage from the integrator 34 again reaches the threshold value, the detection block 36 outputs a further signal to the digital logic 35, indicating that a further quantised unit of charge has been processed.

The digital logic 35 keeps a directional count of the number of threshold detections received until a predetermined number of threshold detections is reached. This predetermined number of threshold detections is also referred to as the logic count value.

Thereafter, the digital logic 35 generates an asynchronous interrupt for processing by the microprocessor 37. The asynchronous interrupt signal includes information about the direction of charge flow.

During the calibration routine, there must be no load placed on the battery 32. During this time, the microprocessor 37 can read data from the digital logic 35, including the direction of charge flow. The microprocessor 37 can also write data to the digital logic 35. An example would be to increase the logic count value, to thereby increase the precision of the offset calculation, given a constant timer resolution. Optionally, the internal, directional count of threshold detections in digital logic 35 could be visible to the microprocessor 37.

Having commenced the calibration routine, the microprocessor 37 calculates an effective offset current for the integrator. It is noted again that this calculation is based on the

measurements taken from the differential amplifier 33 and integrator 34 when no load is placed on the battery 32.

Once the effective offset has been calculated, the microprocessor 37 sets appropriate compensation values.

In another implementation, the microprocessor 37 determines the effective offset with compensation already applied, then change the compensation parameters accordingly.

The following three methods are examples of how the offset compensation for the integrator 34 can be implemented, once the effective offset current value is calculated. These are examples only and it is emphasised that other methods can be used, as will be apparent to those skilled in the art.

1. Variable bias current: a variable bias current source or sink is provided at the integrator input. The bias current has the same magnitude, but with opposite sign, as the equivalent offset current flowing into or out of the integrator. As referred to above, the bias current is set by the microprocessor under the condition of zero charge current, a known state.

2. Software calibration: The effective offset current is measured and an amount of charge, proportional to the offset current, is periodically added or subtracted to the software count of the charge. This is equivalent in magnitude to the periodic interrupt that the microprocessor would receive due solely to the offset error, but opposite in sign. However, this calibration method means that the integration becomes time-dependent, which is undesirable in an asynchronous interrupt-driven system. Also, an increased number of microprocessor instructions are used to store and manipulate time as well as charge data.

3. Variable reset clock: This is similar to the software calibration technique, but implemented in hardware. The frequency of the interrupts generated by the digital logic 35 is measured by the microprocessor 37 under the condition of zero charge flow. A clocking signal is generated which has the same frequency as the threshold resets due solely to the offsets. This is then used as an input to the digital logic 35, and increments or decrements the internal state of the digital logic 35, similar to a threshold reset being generated, but without resetting the integrator 34. In this arrangement the errors due to the differential amplifier 33 and integrator 34 are still present, but are corrected before interrupts are generated for the microprocessor 37. This frees the microprocessor 37 from any additional offset calculation once the clocking frequency is set. The clock generation could be, but is not limited to being, implemented using a relatively fast system clock signal and a programmable clock divider to generate a programmable frequency.

Since offset effects of the differential amplifier 33 and integrator 34 are compensated for, the measurement is useful even if a small current load is presented to the battery 32.

The re-settable measurement circuit relies on the device being temporarily powered from a power supply other than the battery 32. This temporary calibration time may be in the order of 30 seconds.

The main advantage of performing calibration in this way is that it may be performed at any time when an external power supply is available, typically when charging. Therefore, the offset compensation maintains its accuracy over the entire range of current when charging or discharging and ensures that errors do not accumulate over time.

Also, since the offset compensation is calculated during zero load periods, no pre-testing is required.

The re-settable measurement circuit can be incorporated into a charge management algorithm, as will be later described. It is noted at this stage that in such an algorithm, the external conditions such as sufficient external power and zero charge current, are assumed to be appropriate for the duration of calibration.

The techniques according to this disclosure can compensate for battery self-discharge and thus can be applied to a relatively wide range of battery technologies. Self-discharge is more significant in older technologies.

Li-Ion technology, for example, is very sensitive to certain parameters. For instance over-charge and over-discharge may result in permanent damage and reduced performance for all rechargeable chemistries. The performance of the battery is also dependent on the level of charge stored on the battery when operating within the operating limits.

Further, the processing burden is minimised, given that a combination of analogue and digital techniques is used. It is also noted that this benefit is further realised through the use of interrupts to the microprocessor, rather than processor polling. So instead of a processor periodically recording how much charge has accumulated, an interrupt is generated, which tells the processor that a quantised unit of charge has been received. This event may occur relatively infrequently, requiring minimal processor time to store this information.

The techniques according to this disclosure can be advantageously used with devices powered by batteries with a processor used in part for battery charge management. It is particularly applicable to situations where an algorithm must determine the charging regime for the battery. That is, to preserve battery life, the battery may not necessarily be charged even if it is possible to do so.

The techniques according to this disclosure make some attempt at minimising errors at the design level, but accept them as being finite and non-zero. Under a no-load condition, these errors are quantified. Then, during measurement, an error compensation technique minimizes the error. That is, it can be calibrated during operation.

Turning now to Fig. 3, an example of how the re-settable measurement circuit of Figs 2 and 3 can be incorporated into an algorithm, is described.

Proceeding to step 301, the integrator is initialised, the digital logic internal count is reset, and the digital logic is placed in calibration mode before advancing to step 302 in which the output of the integrator 34 is monitored. During step 301, the microprocessor starts a timer, for use later when determining effective current.

The voltage output of the integrator 34 is continuously checked for comparison with a threshold voltage at step 303.

Once the threshold voltage value has been reached, step 304 is taken to reset the integrator 34 and to increment the digital logic internal count.

Next at step 305, the digital logic internal count is checked for having reached a calibration count limit value and until this is reached, the output of the integrator 34 is continued to be monitored by reverting back to step 302.

However, once the digital logic internal count has reached the calibration count value, the digital logic circuit 35 generates an interrupt for the microprocessor at step 306.

The microprocessor processes this interrupt at step 307, by recording a timer value and placing the digital logic circuit 35 back in measurement mode, for future current measurements.

At step 308, the microprocessor calculates the effective offset current on the basis of the recorded timer value and the amount of current represented by the calibration count value. Current is charge per unit time. Although this charge has been measured, it did not actually flow into or out of the battery.

At step 309, the microprocessor takes steps to compensate for the measurement offset as earlier described, and the calibration routine ends at step 310.

Referring now to Fig. 4, an example of a charge management algorithm, for charging and discharging a battery, incorporating the re-settable measurement circuit of Figs 2 and 3 will be described. It is noted that this is provided as an example, and the methods outlined above are not limited to this particular algorithm, which is based on the constant current/constant voltage method. Other algorithms could be based on constant power and fast charge methods, including pulse charging.

In summary, the charge management algorithm first discharges the battery 32 to a known state, then uses the method of constant current, then constant voltage to initially charge the battery. During this time, the amount of charge delivered to the battery is recorded. The battery is then cycled using the amount of charge stored as a measure of the useful energy left in the battery. This process is repeated after a number of cycles to eliminate any accumulated error due to imprecise charge integration.

The algorithm commences by initialising the following variables:

VOLTAGE THRESHOLD – set at say between 2.0 and 6.0 Volts (reached by applying constant charging current).

CHARGE CURRENT – set with a maximum allowable constant charging current value. Typically, the current limit is programmable in steps, for example in 0.5mA steps, from zero to the maximum allowable constant current value.

CURRENT THRESHOLD – set at a proportion of the capacity C of the battery, say between C/10 and C/100. The value stored in this variable represents a lower limit of **CHARGE CURRENT**, and is used to determine the end point of the constant voltage process.

CHARGE COUNTER (Q) – a directional count of the number of charge interrupts generated by digital logic 35, which thus represents a cumulative value of charge. This variable is initially set to zero.

Q_LOWER – represents a lower value of charge reached during the operation cycle.

Q_UPPER – represents an upper value of charge reached during the operation cycle.

CYCLE COUNTER - holds value of cycles and is initially set at zero.

CYCLE COUNT LIMIT - set to say between 20 and 100 cycles.

OFFSET COMPENSATION - set to zero, unless there is an existing valid value, in which case that value is retained.

After initialisation, step 402 is proceeded to, in which a constant charging current is applied to the battery 32 in accordance with the value stored in **CHARGE CURRENT**.

Throughout the algorithm, except during calibration at step 407, the value stored in **CHARGE COUNTER (Q)**, which reflects the cumulative amount of charge delivered to the battery, is incremented or decremented accordingly.

Once the battery voltage reaches the value stored in **VOLTAGE THRESHOLD,** the constant voltage charge phase is commenced. Here the voltage is maintained but the current is decreased until it reaches the value held in **CURRENT THRESHOLD.**

As a safety feature, the maximum voltage of the battery during charging is limited by hardware and can therefore never be exceeded. When **VOLTAGE THRESHOLD** is set to a lower

value than the hardware limit, the charge current can be limited by the microprocessor. Another safety feature of the algorithm is that if the **CHARGE COUNTER (Q)** falls below zero during discharge, the device may treat this as an error condition and reset itself accordingly.

An example of the result is shown in Figs. 5A & 5B, in which it can be seen that the constant current charge is applied to the battery until the terminal voltage reaches a threshold voltage. Thereafter, the current is repetitively decreased and the battery is charged until the terminal voltage again reaches the threshold voltage. This allows the internal chemistry to settle to a steady state. Hence, the battery can subsequently be discharged under well-defined conditions from an unknown state of charge to a well-defined cut-off voltage.

The discharging could be iteratively reduced by a fraction in one arrangement. However, the charge current should usually not fall below a limiting value specified by the manufacturer, in order to avoid accelerated battery fading.

The constant voltage phase is protected against indefinite charging, which could result in permanent loss in performance.

As the battery fades, the constant current phase becomes shorter and the constant voltage phase becomes longer. The battery starts to accept the charge at a slower rate.

Once the current decreases to the value held in **CURRENT THRESHOLD**, a single charging cycle is completed and thus allows the integrator offset calibration to be implemented. This occurs when the method proceeds to step 406.

At step 406, the value stored in **CHARGE COUNTER (Q)**, which now reflects a cumulative quantity of charge stored in the battery, is used to calculate values that are written to **Q_LOWER** and **Q_UPPER**. These calculated values will vary over time as the battery fades, since the accumulated charge stored in **CHARGE COUNTER (Q)** will decrease, for the same voltage and current thresholds.

The value stored in **CHARGE COUNTER (Q)**, for the first execution of the algorithm loop, could be incorrect due to calibration not having been performed. Since the calibration will be performed before the second execution, this effect will only be applicable for a short period of device operation.

Next at step 407, the integration function can be calibrated by correcting any offset error, as explained previously, if sufficient external power is available for the device to function. This is a requirement, as no load must be placed on the battery during calibration. At this stage the offset compensation parameters are written to **OFFSET COMPENSATION.**

After the calibration of step 407 is completed, step 408 is proceeded to. At step 408, the battery is allowed to discharge until the value stored in **CHARGE COUNTER (Q)** is equal to the value stored in **Q_LOWER**. Thereafter, the **CYCLE COUNTER** is incremented.

At step 409, the battery is again charged until the value of **CHARGE COUNTER (Q)** is equal to the value stored in **Q_UPPER**.

Thereafter the process is handed over to step 408 and the cycle repeats. This cycle results in an oscillation between a minimum and maximum charge counter value.

An example of the cycling performed by steps 408, 409, 410 and 411 is shown in the graph of Figs. 6A & 6B. These subsequent discharge and charge actions may be partial.

Step 412 is proceeded to when **CYCLE COUNTER** is equal to **CYCLE COUNT LIMIT**, as determined by step 410.

The process of recalibrating the measuring circuit occurs at around every 20 to 100 operating (charge/discharge) cycles of the algorithm. In this context, it is noted that any charge followed by a discharge event is referred to as a cycle and does not imply full charge or full discharge of the battery.

In the case of charging power becoming unavailable as determined in step 411, the method proceeds to step 412.

At step 412, the battery is discharged to a well-defined cut-off voltage. This limitation protects the battery against damage from over discharging. This cut-off voltage is typically specified by the battery manufacturer, and is dependent on the battery technology used.

At step 413, the presence of charging power is determined. If there is no charging power available, then the method ends by proceeding to step 420. Otherwise the method proceeds to step 401 and the method continues.

The algorithm described above, which incorporates the re-settable measurement circuit, is relatively aging-independent and can therefore provide the following advantages.

1. Improved battery cycle life: This occurs because the techniques described herein can allow the battery to be operated within its designed limits, but closer to maximum performance. Also, the time for the battery to discharge before an external supply is required to power the electronic device can be made longer without adversely affecting battery longevity.

Generally, each type of battery technology requires that the battery charge be maintained between minimum and maximum voltage levels (e.g. 3.0V and 4.2V). Exceeding these limits may result in permanent damage and loss in performance and the extent of damage is a function of voltage and time. Once these limits have been exceeded, proper

function of the battery cannot be guaranteed. The upper voltage limit in particular is very important in order to avoid damage to the battery, in the case of a lithium ion battery.

2. Improved battery longevity: the battery longevity can be preserved by knowing the aging state of the battery i.e., when the battery is new, it is operated in more shallow cycles which is generally better for longevity. When the battery is older, the cycle life could be preserved, as any additional aging, due to deeper cycling, will be less significant.

3. Improved user knowledge: The techniques described herein can be used to indicate how long the electronic device can function without charging, thus enabling the user to make more informed choices about usage patterns, to increase battery life.

4. Minimise processing burden, despite varying current. The interrupt routine simply increments or decrements a charge counter every few seconds (or longer) and thus requires very little processing power. This is critical in a cochlear implant, for example, where the processor has a high utilisation, and all instructions are optimised.

The characterising method according to this disclosure is particularly suitable for low powered applications such as medical devices. In particular, it is envisaged that the techniques described herein can be advantageously used in devices where the battery is implanted in the human body. This situation brings in special challenges, as the battery is not easily replaceable and physical space must be minimised as far as possible. Accordingly, it is also desirable to keep the processing burden to a minimum.

An example of an implantable medical device which could benefit by using the techniques according to this disclosure is a totally implantable cochlear implant. Such an implant is described for example in WO 02/05590.

Turning to Figs. 7 and 8, a cochlear implant 40 adapted for implantation in the temporal bone adjacent the ear comprises a coil 46, microphone 42, rechargeable battery 43 and speech/stimulation processor incorporated within a single integrated device.

The coil 46 also acts a power receiver and so provides a means of inductively charging the battery 43 through the RF link. However, the implant 40 is capable of operation whilst the battery 43 is being recharged.

Further, the coil 46 acts as a RF link to allow bidirectional data transfer between the implant 40 and external devices.

Referring to Fig. 9, the electrical architecture 50 of the cochlear implant 40 is based on a microcontroller 58 which performs the main control functions. An internal audio signal path includes the internal microphone 42, front end 51 and sound processor 53. The external

stimulus and control data path includes an RF Link (antenna coil) 46, RF Controller 54, data encoder 56, output controller 59 and cochlea electrodes 63.

An external controller 76 is also provided, having a battery charger 72 and auxiliary sound processor 71. The battery charger 72 provides a means of inductively recharging the implanted battery 43 through the RF link 73 when required. The external sound processor 71 can be used when the implanted processor is inactive for any reason and can provide wider sound coding algorithm options. The external controller can also provide a means of interrogating the implant 40 to determine the level of charge of the battery 43.

A supply and bias block 65 provides power on reset to ensure all circuits start up in a controlled state at power up. The block 65 also provides charge management, to ensure that the battery charge cycles are properly maintained, supply voltage monitoring to ensure functional operation of and data retention, and voltage regulation.

The block 65 also includes reference generators. The block 65 also ensures that low noise bias currents are distributed to the analog functions.

There can also be provided a deactivation means which provides a means of quickly and safely deactivating the implant 40, without the delay and inconvenience of having to locate and activate the external controller. On detection of operation of the deactivation means, the microcontroller 58 places the implant 40 in a standby mode where all electrical stimulation to the electrodes 63 is discontinued. If the implantee again operates the deactivation means, the microcontroller 58 shuts down operation of the implant 40. The implant 40 can then only be re-activated through use of the external controller.

The techniques described herein may be implemented as software executing on a computer, such as the microcontroller 58. Such software may be stored in a computer readable medium, including storage devices such as: a floppy disc, a hard disc drive, a magneto-optical disc drive, CD-ROM, magnetic tape or any other of a number of non-volatile storage devices well known to those skilled in the art.

The software is loaded into the computer from the computer readable medium, and then executed by the computer. A computer readable medium having such software or computer program recorded on it is a computer program product. The use of the computer program product in the computer preferably effects an advantageous apparatus for managing the charging and discharging of a rechargeable battery in accordance with the techniques described herein.

It will be appreciated by persons skilled in the art that numerous variations and/or modifications may be made to the invention as shown in the specific embodiments without

departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects as illustrative and not restrictive.

Aspects of the invention:

1. A method of managing a power supply for an electronic device, the power supply having a rechargeable battery source and an auxiliary power source, said method comprising the steps of:

implementing a measuring circuit to measure parametric data of the battery source during operational charging and discharging cycles with the device;

checking for temporary removal of the battery source from operation of the device; and

testing the measuring circuit for offset error, if power from the battery source has been temporarily removed, before resuming said implementing step.

2. The method according to paragraph 1, wherein said testing step further comprising the sub-step of correcting the measuring circuit in the case of an offset error.

3. The method according to paragraph 1 or paragraph 2, wherein the device can be temporarily powered by the auxiliary power source during said testing step.

4. The method according to any one of the preceding paragraphs, wherein said parametric data includes cumulative charge.

5. A power supply for an electronic device, said power supply comprising:

a rechargeable battery source configured for cyclical charging and discharging during operative association with the electronic device;

a measuring circuit for measuring parametric data during said charging and discharging;

an auxiliary power source being able to power the electronic device independently of said battery source; and

a testing circuit for testing said measuring circuit for offset error;

a disconnection circuit for temporarily removing said operational association of said battery with said device;

wherein said testing circuit is enabled during said temporary removal of said operational association of said battery with said device.

6. The power supply according to paragraph 5, wherein said testing circuit corrects any offset error before said operational association of said battery with said device is restored;

7. The power supply according to paragraph 5 or paragraph 6, wherein said parametric data includes cumulative charge.

8. A system for operating a rechargeable battery, said system comprising:

current maintaining means for maintaining a substantially constant current to the battery until the battery reaches a predetermined maximum voltage;

voltage maintaining means for maintaining a substantially constant voltage to the battery until a predetermined minimum current is delivered to the battery;

determining means for determining a cyclical charge value delivered to the battery by said current maintaining means and said voltage maintaining means during a cycle; and

correction means for correcting said determining means when charge is not being delivered to the battery, on the basis of said charge value.

9. The system according to paragraph 8, wherein said voltage maintaining means is operative after the battery reaches said predetermined maximum voltage by said current maintaining means.

10. The system according to paragraph 8 or paragraph 9, wherein said determining means comprises a current integration means for integrating current delivered to the battery.

11. The system according to any one of paragraphs 8 to 10, wherein said predetermined maximum voltage is less than 10 Volts.

12. The system according to any one of paragraphs 8 to 11, wherein said predetermined minimum current is less than 20 mA.

13. The system according to any one of paragraphs 8 to 12, wherein the rechargeable battery is used for an implantable medical device.

14. The system according to any one of paragraphs 8 to 13, wherein the implantable medical device is a cochlear implant.

15. The system according to any one of paragraphs 8 to 14, wherein the cochlear implant is a totally implantable cochlear implant.

16. An apparatus for characterising a rechargeable battery, said apparatus comprising:

a constant current source for maintaining, during a first charging stage, a substantially constant current flow to the battery, until the battery reaches a predetermined maximum voltage;

a constant voltage source for maintaining, during a second charging stage, a substantially constant voltage to the battery, until a current flow delivered to the battery falls to a predetermined minimum;

an integrator for integrating said current flow delivered to the battery during the first and second calibration stages;

threshold detection means configured to signal a unit count of charge upon detection of a predetermined level of charge indicated by the output from the integrator;

correlation means for correlating a total number of unit counts of charge during said first and second calibration stages with said predetermined maximum voltage and said predetermined minimum current.

17. The apparatus according to paragraph 16, wherein said second calibration stage commences after completion of said first calibration stage.

18. A computer readable medium, having a program recorded thereon, where the program is configured to make a computer execute a procedure to operate a rechargeable battery, said procedure comprising the steps of:

characterising the battery comprising the sub-steps of:

(i) delivering a substantially constant current to the battery until the battery reaches a predetermined maximum voltage;

(ii) delivering a substantially constant voltage to the battery until a predetermined minimum current is delivered to the battery; and

(iii) determining a delivered charge value delivered to the battery by sub-steps (i) and (ii);

cyclically delivering operational charging and discharging of the battery according to said determined delivered charge value.

19. A system for operating a rechargeable battery, said system being substantially as described herein with reference to Fig. 2.

20. A method of operating a rechargeable battery, said method being substantially as described herein with reference to Fig. 3.

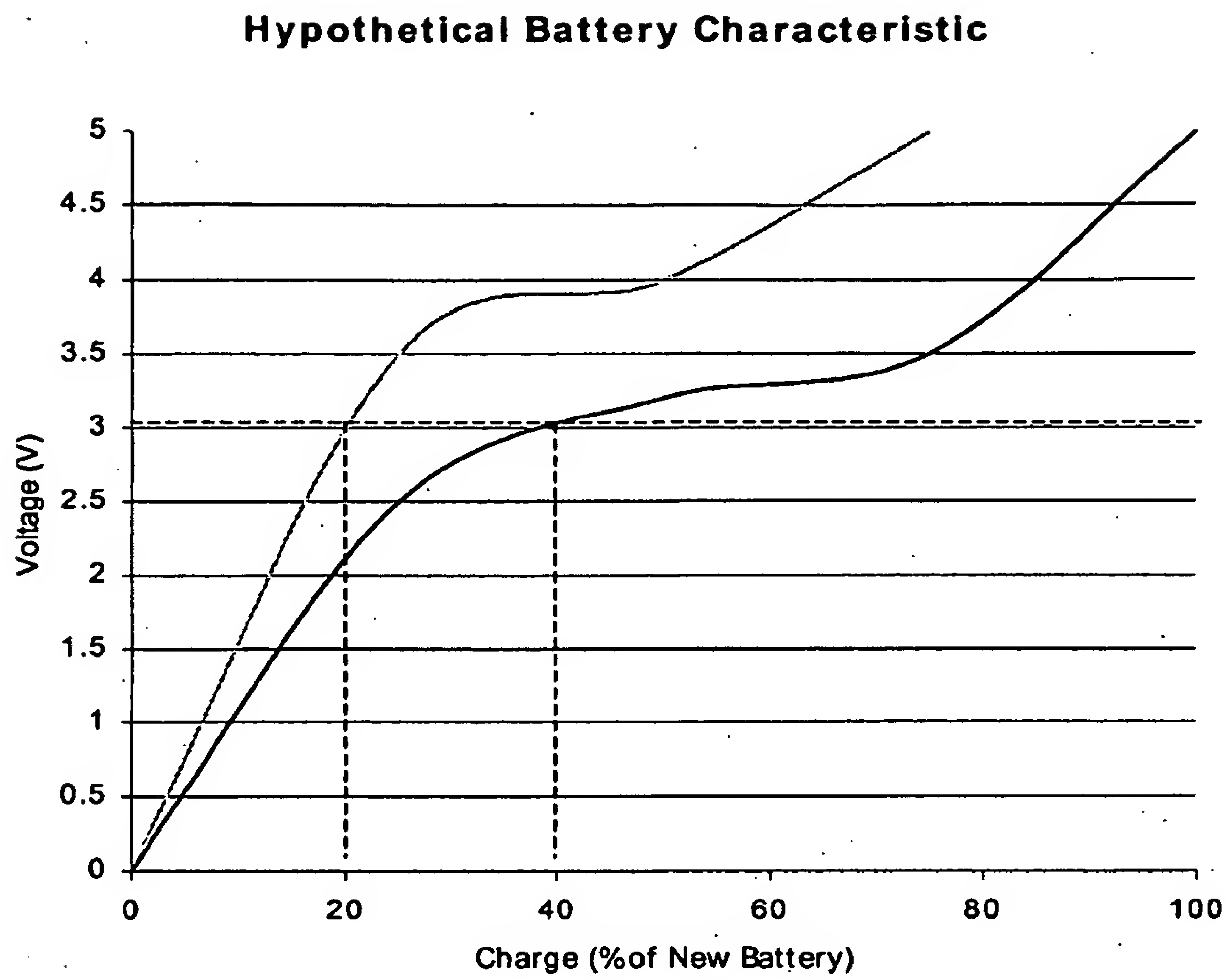

Hypothetical Battery Characteristic
Voltage (V)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
20
40
60
80
100
Charge (%of New Battery)

FIG. 1

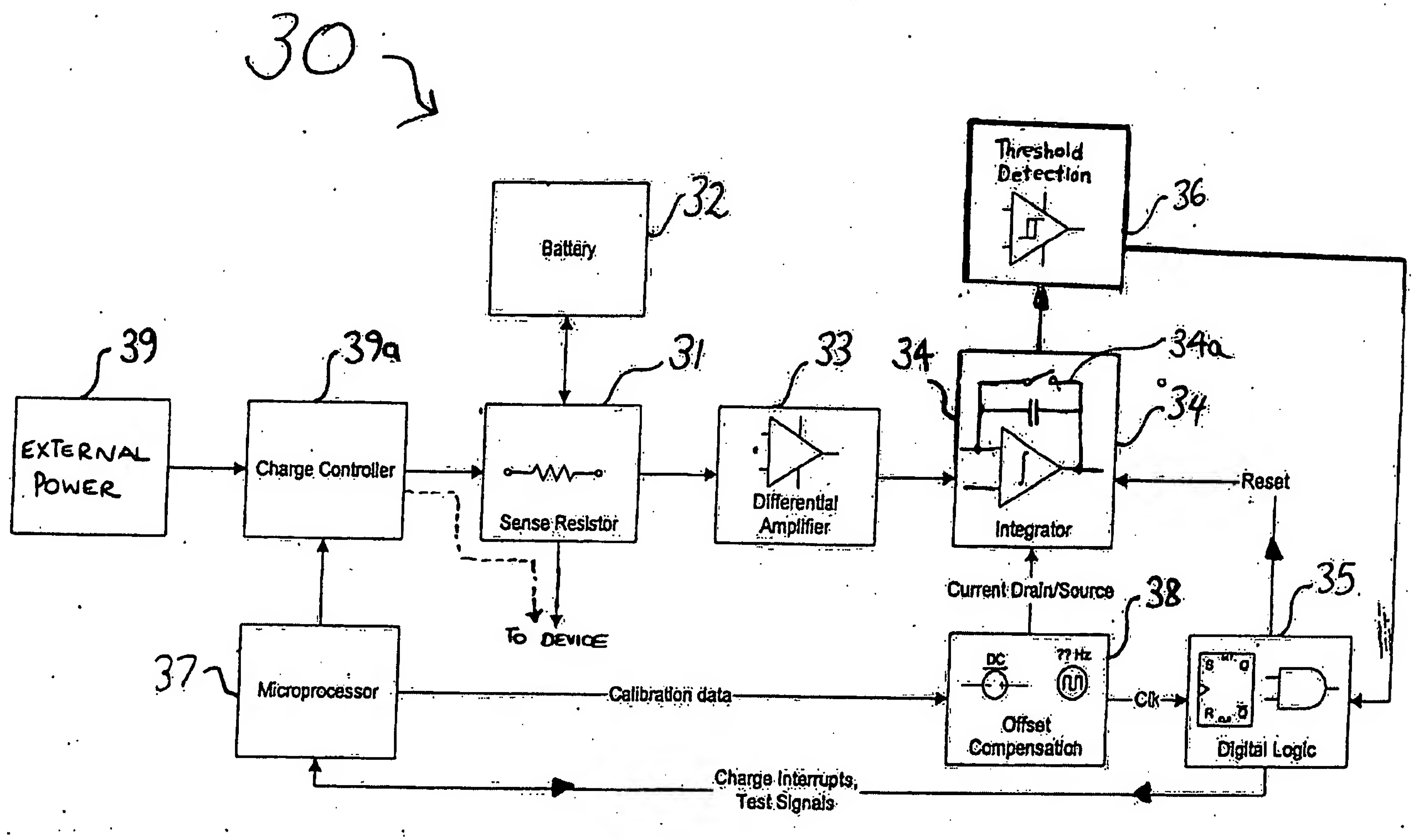

30
EXTERNAL POWER
39
Charge Controller
39a
Battery
32
Sense Resistor
31
To DEVICE
Differential Amplifier
33
Integrator
34
34a
34
Threshold Detection
36
Reset
Current Drain/Source
38
DC
?? Hz
Offset Compensation
Clk
Digital Logic
35
Microprocessor
37
Calibration data
Charge Interrupts, Test Signals

FIG 2

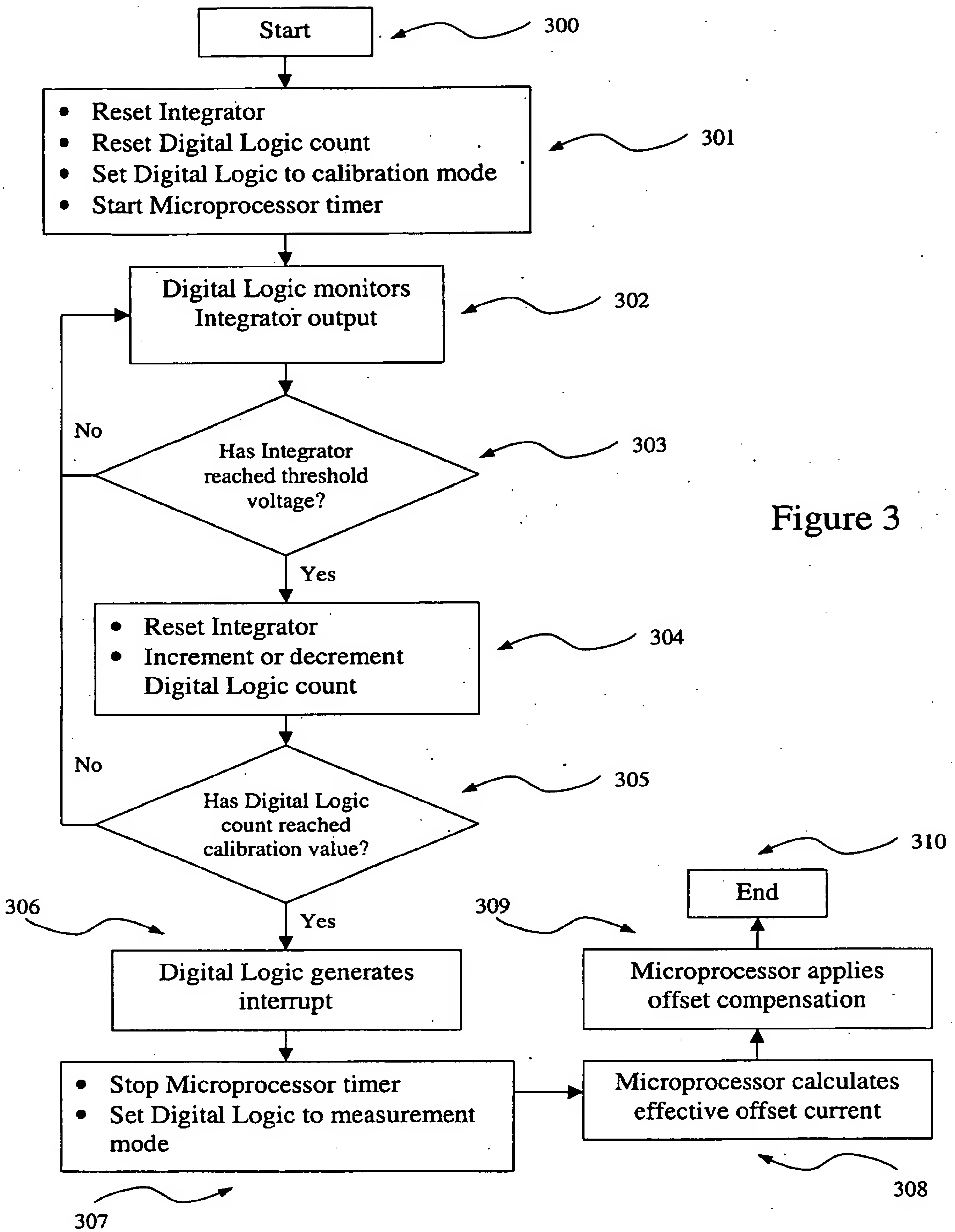

Start
300
Reset Integrator
Reset Digital Logic count
Set Digital Logic to calibration mode
Start Microprocessor timer
301
Digital Logic monitors Integrator output
302
No
Has Integrator reached threshold voltage?
303
Yes
Reset Integrator
Increment or decrement Digital Logic count
304
No
Has Digital Logic count reached calibration value?
305
Yes
306
Digital Logic generates interrupt
Stop Microprocessor timer
Set Digital Logic to measurement mode
307
Microprocessor calculates effective offset current
308
Microprocessor applies offset compensation
309
End
310

Figure 3

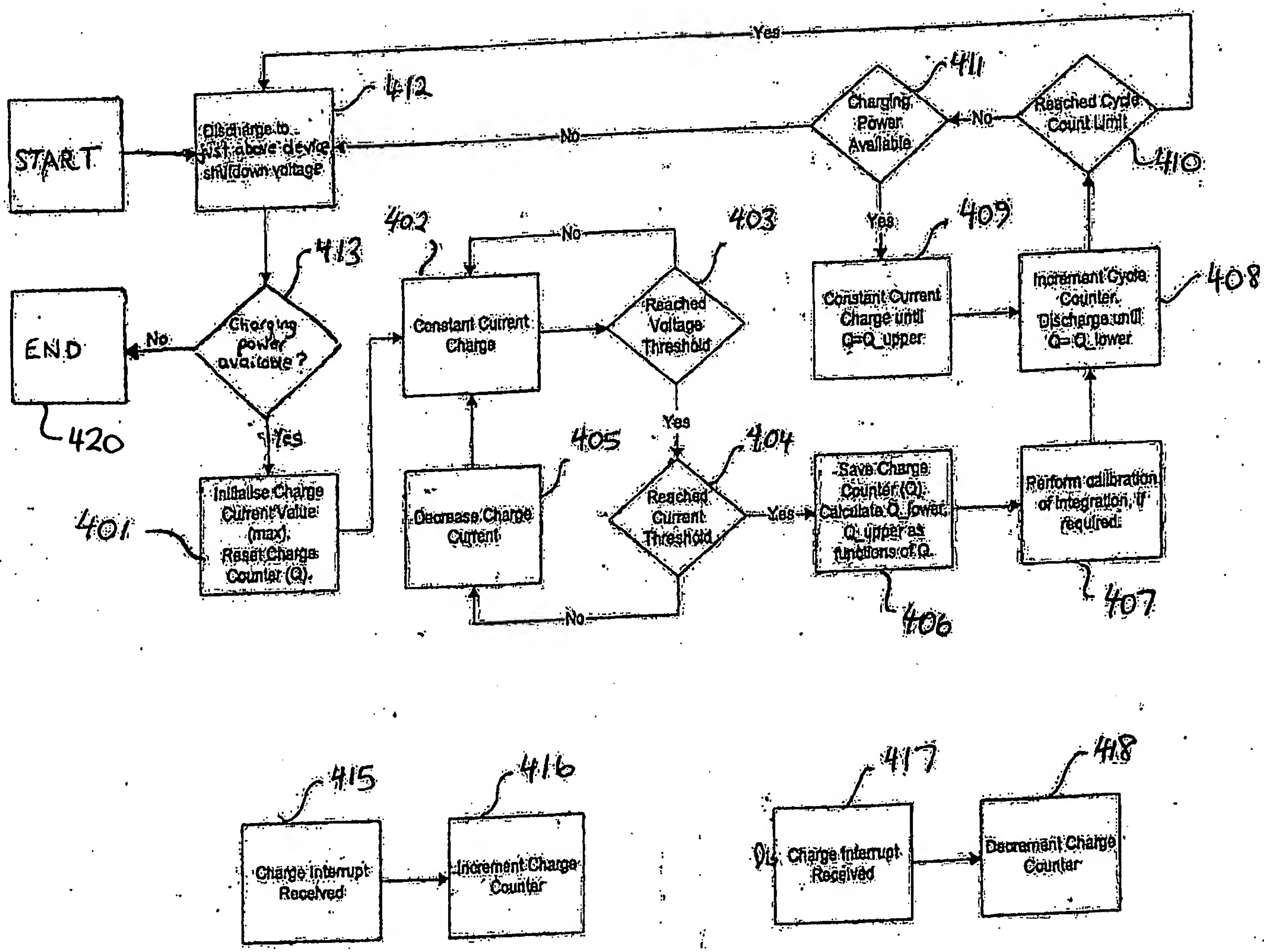

START
Discharge to just above device shutdown voltage
412
Charging power available ?
413
No
END
420
Yes
Initialise Charge Current Value (max). Reset Charge Counter (Q).
401
Constant Current Charge
402
No
Reached Voltage Threshold
403
Yes
Decrease Charge Current
405
Reached Current Threshold
404
No
Yes
Save Charge Counter (Q). Calculate Q_lower, Q_upper as functions of Q.
406
Perform calibration of integration, if required.
407
Increment Cycle Counter. Discharge until Q=Q_lower
408
Reached Cycle Count Limit
410
No
Yes
Charging Power Available
411
No
Yes
Constant Current Charge until Q=Q_upper
409
Charge Interrupt Received
415
Increment Charge Counter
416
Charge Interrupt Received
417
Decrement Charge Counter
418

FIG. 4

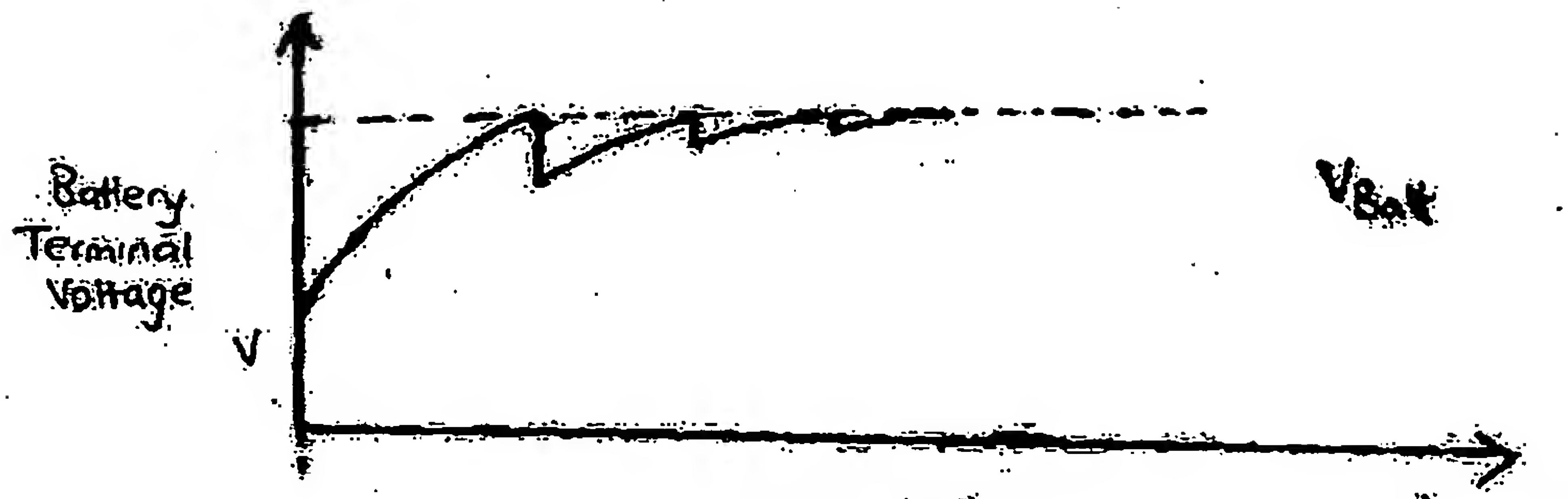


FIG. 5A

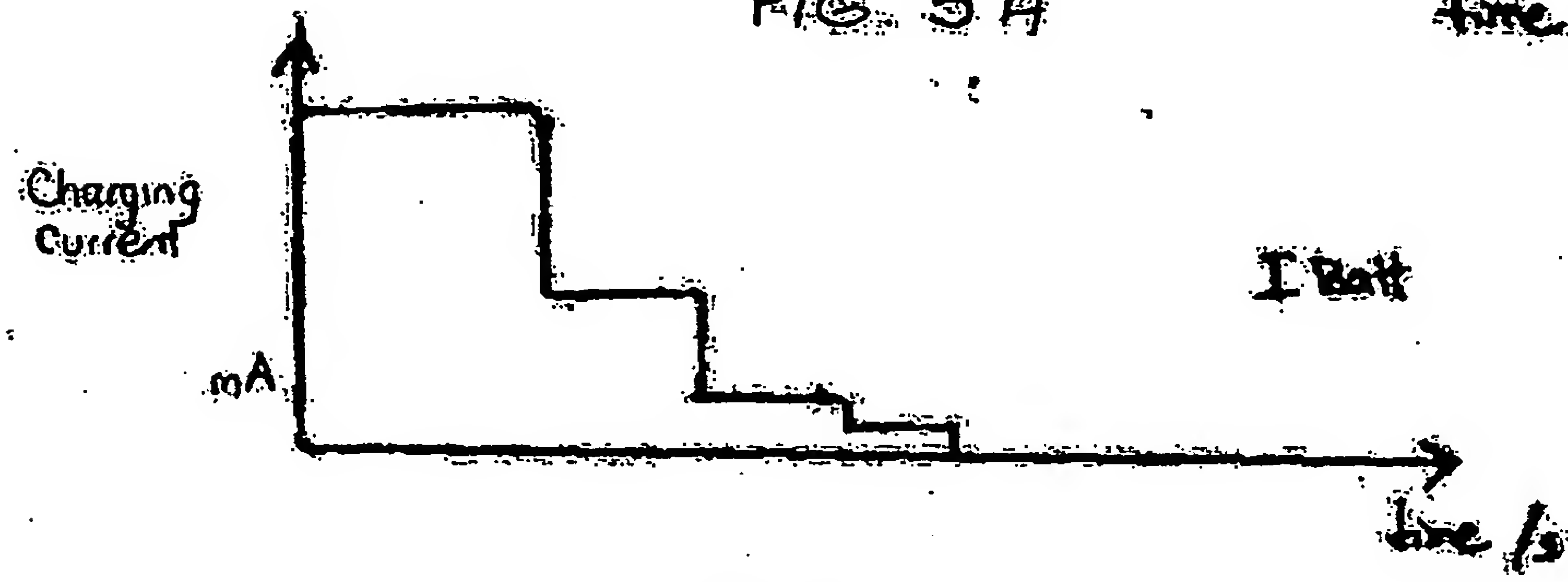


FIG. 5B

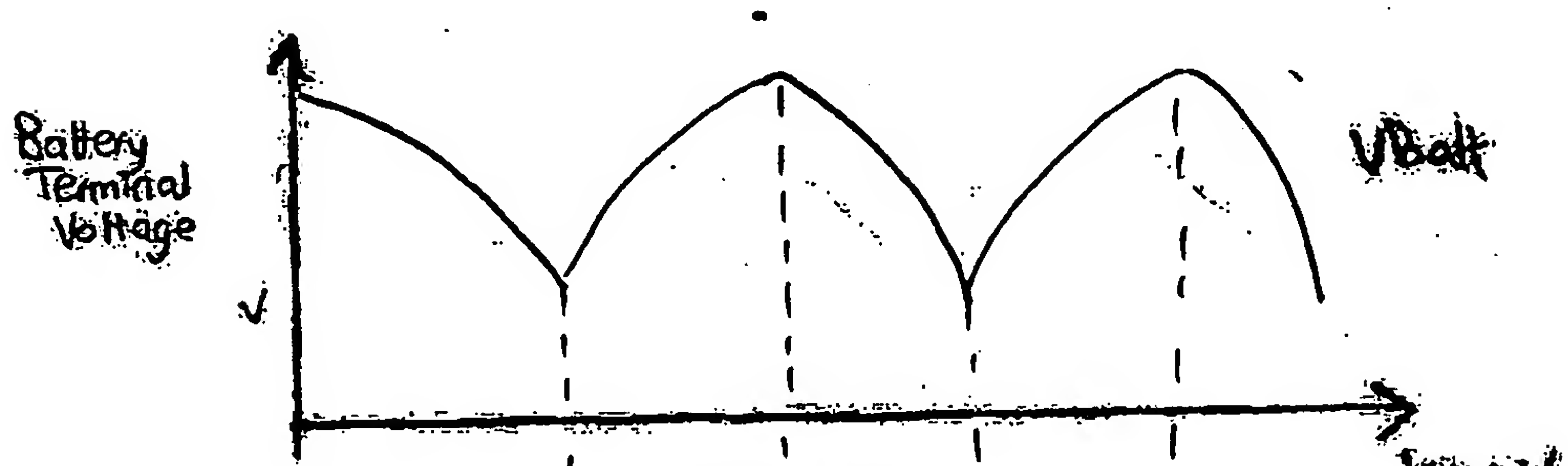


FIG. 6A

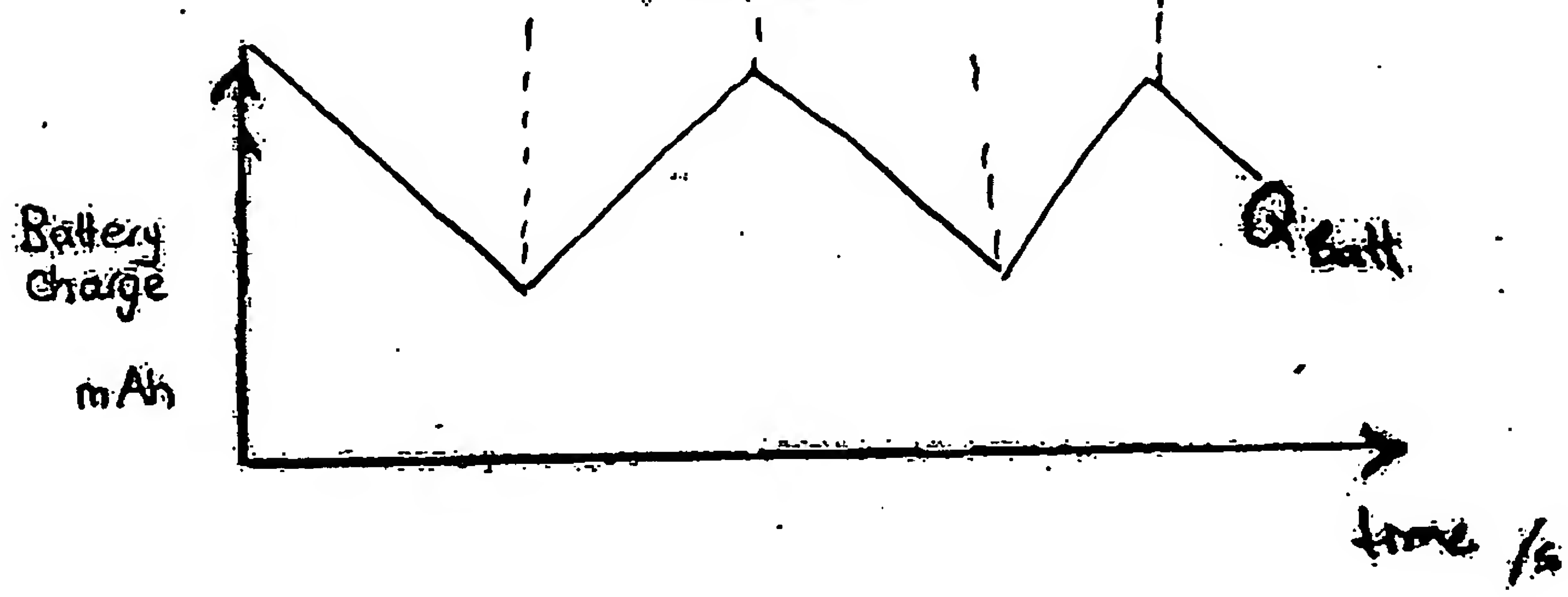


FIG. 6B

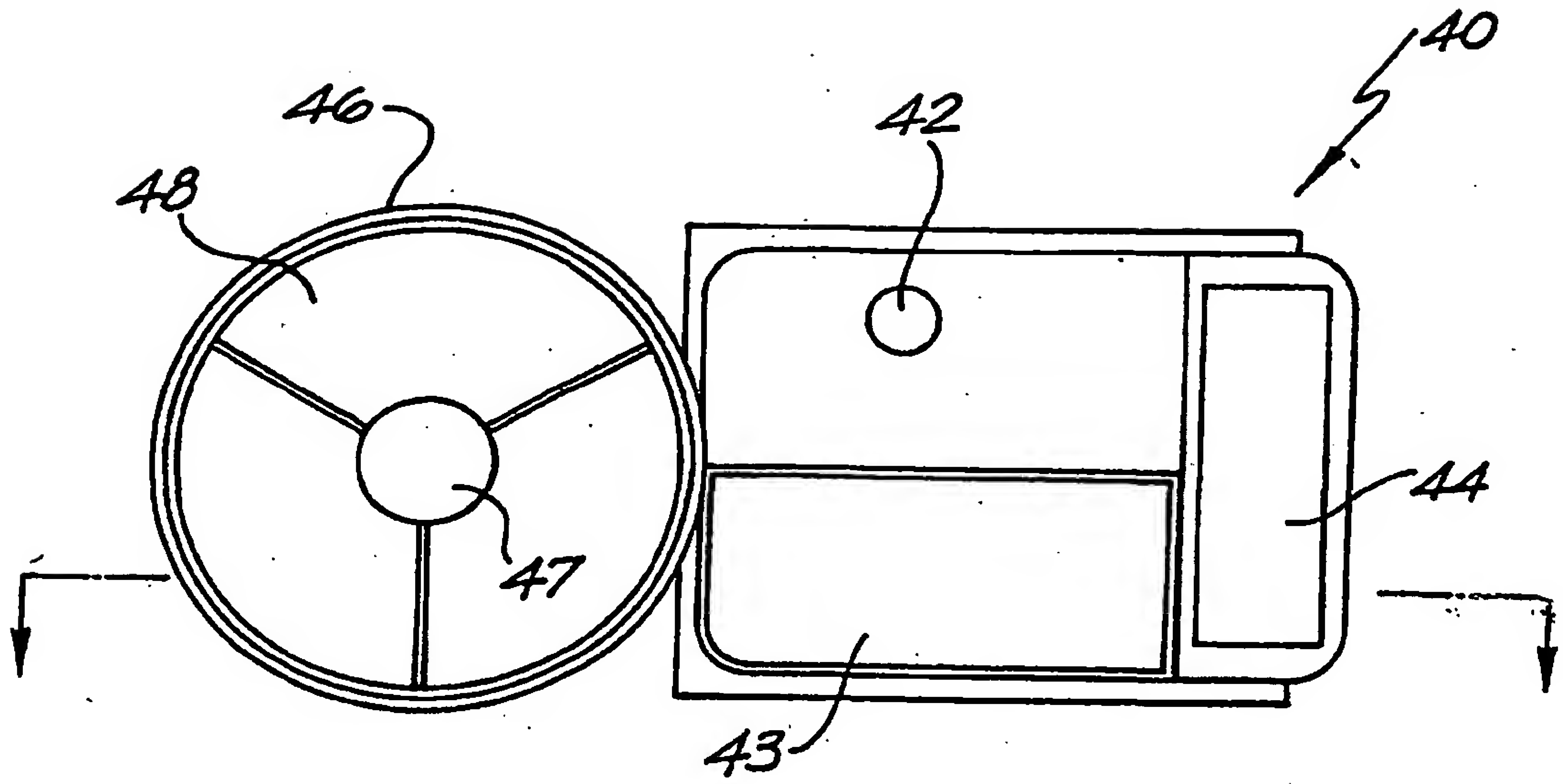


FIG. 7

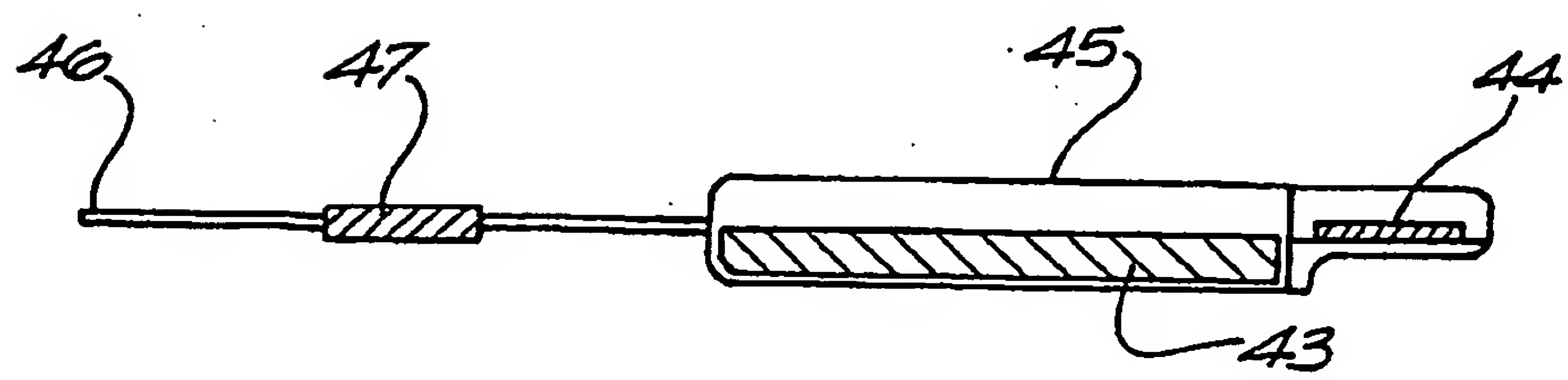
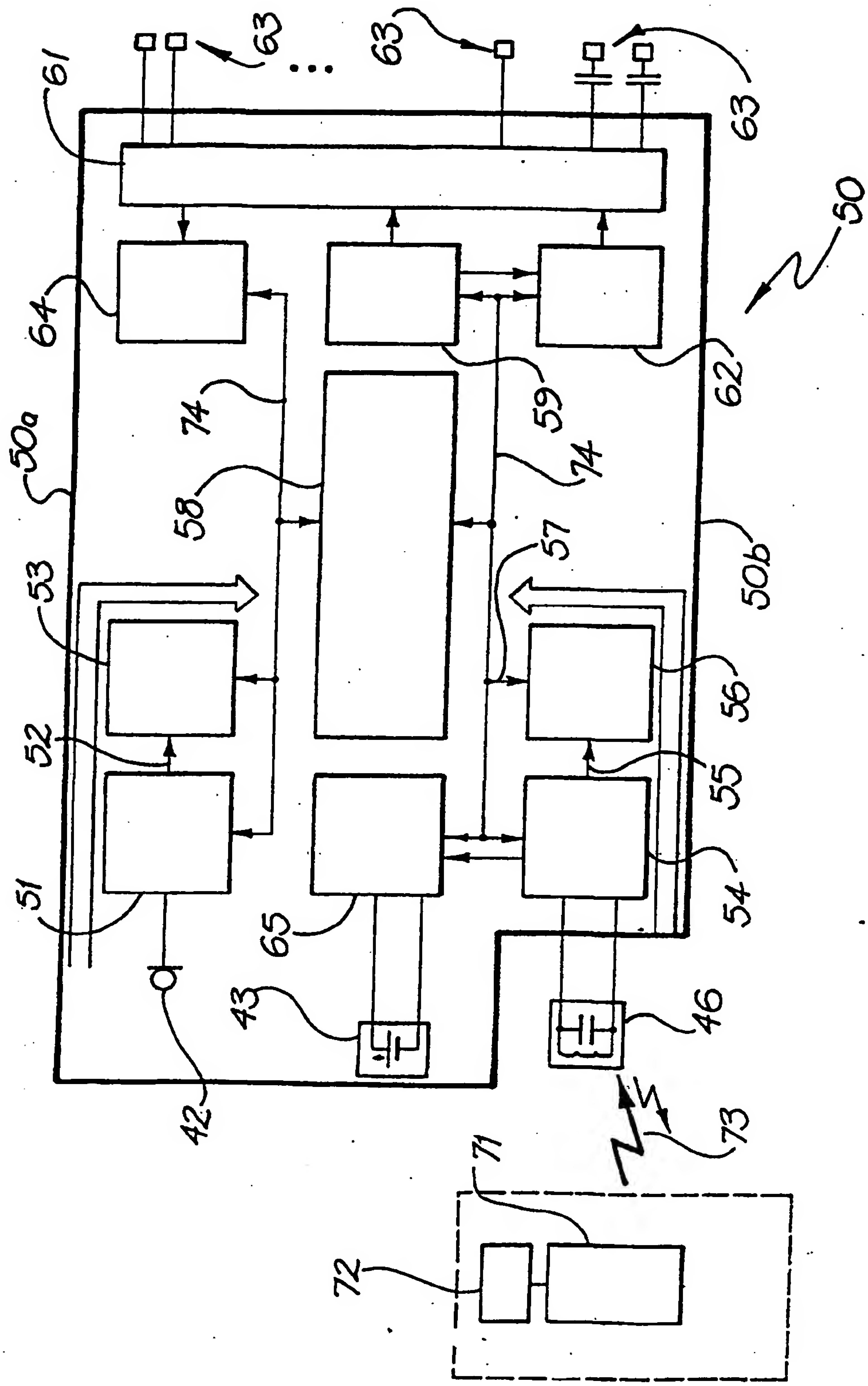


FIG. 8


61
63
63
63
50
64
74
59
62
50a
58
74
57
53
50b
52
56
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51
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43
46
42
73
71
72

FIG. 9

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